Feasibility Study for Improvement of Efficient Irradiation with LEU Core in JMTR

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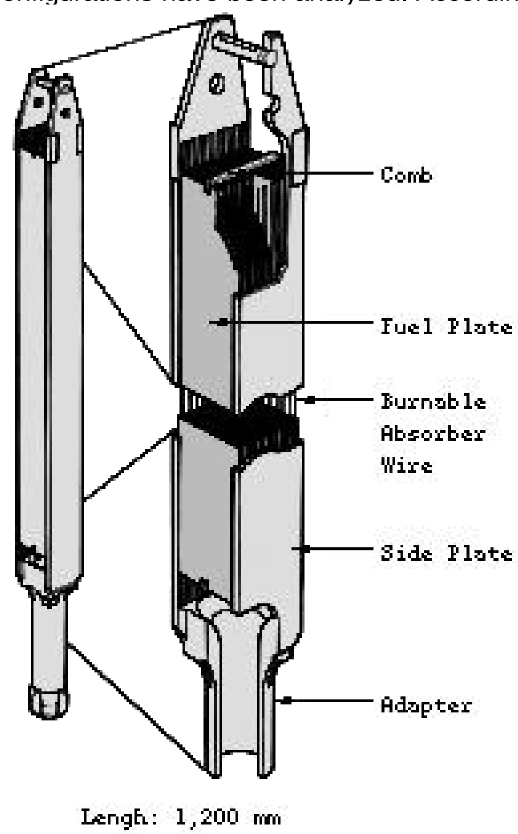
Abstract

The JMTR of JAERI is currently operated in 4 to 5 cycles a year, for continuous full power operation of 25 days in each cycle by using LEU and, partially, MEU fuel elements. After finishing the use of stocked MEU fuel elements in the next year, the JMTR will be operated by using only LEU fuels.

In order to enhance irradiation capability and to improve fuel economy, it is planned to employ improved core configuration with higher fuel burn-up. The objective of this improvement is to achieve drastic increase of annual operation days without changing thermal power and increasing annual consumption of the fuels.

Nuclear and thermal characteristics of several core configurations have been analyzed. According to the result of neutronic calculation, the JMTR c
employing a core composed of 3 batches (fresh,
elements, without increase the number of annual cc
After such improvement, the averaged burn-up of
neutron flux in irradiation region will not significantly c



1. Introduction

The Japan Materials Testing Reactor (JMTR) [1] is located in Oarai Research Establishment of the Japan Atomic Energy Research Institute (JAERI). The JMTR is a tank-in-pool type reactor with thermal power of 50 MW which is corresponding to the power density of about 500 kW per litre. It has been contributing to research and

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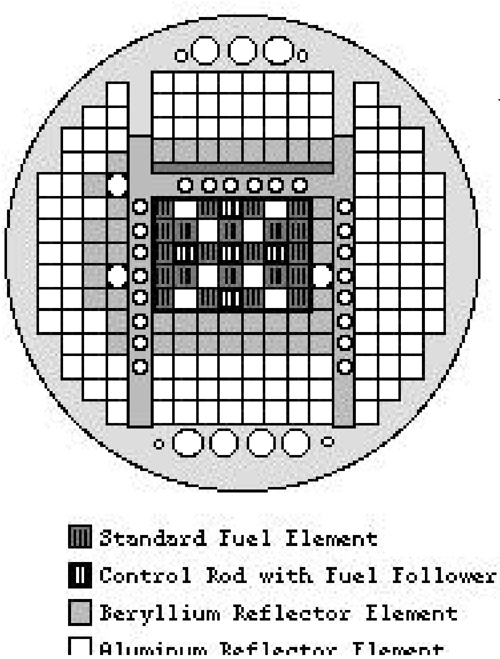

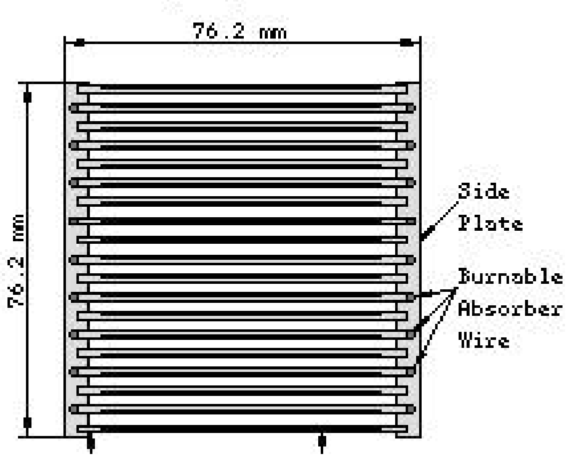

Recently, higher neutron fluence irradiation test in the JMTR is demanded for the development of blanket and structural materials of the fusion reactor and the research of irradiation assisted stress corrosion cracking (IASCC) for LWRs, etc. It is strongly desired to increase annual operation days in the JMTR in order to enhance irradiation capability, as well as to improve LEU fuel economy. Accordingly, it is planned to employ improved core configuration with increasing burn-up of the LEU fuel. Nuclear and thermal characteristics have been analyzed in the JMTR about several candidate configurations of the core.

2. Effective Use of LEU Fuels in JMTR

The JMTR is currently operated in 4 to 5 cycles a year, for 25 days in each cycle by employing so called MEU6 core[4][5]. The MEU6 core consists of 6 MEUs, 16 LEUs (8 elements per batch, 2 cycle used) and 5 follower LEUs. Averaged burn-up of each fuel element are about 30% or less. After finishing the use of MEUs in the next year, it is planned to operate the JMTR by using only LEU fuels

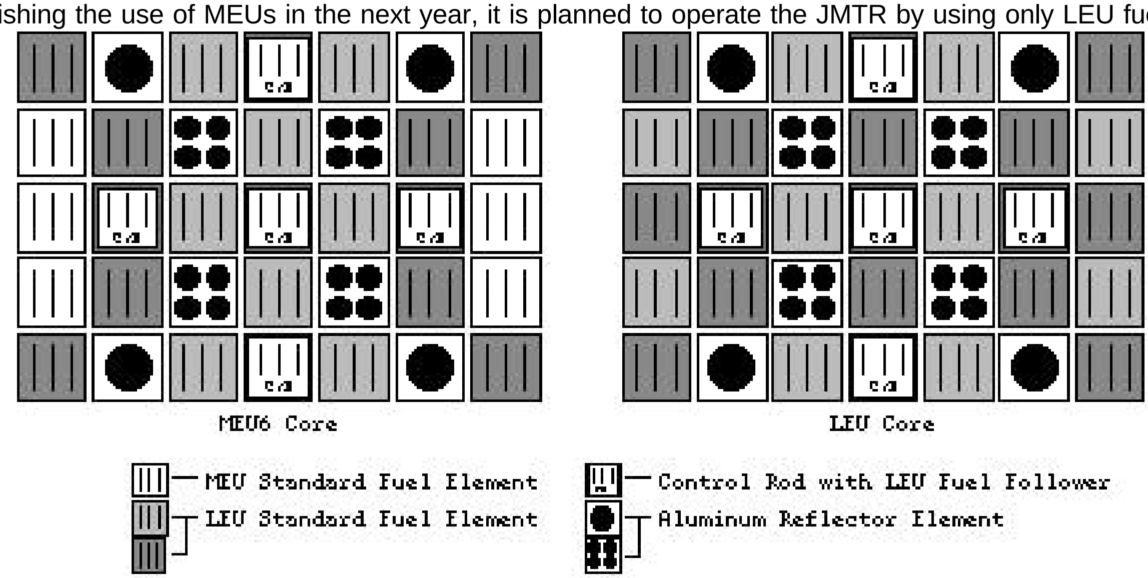

Fig. 2-1 Fuel Arrangements of MEU6 Core and LEU Core

with core configuration described in the current reactor license, in which 22 LEUs are used in 2 batches (10 or 12 element per batch). Fuel arrangements of the MEU6 core and the licensed LEU core[3] are shown in **Fig. 2-1**. Duration of one operation cycle will be the same as present, i.e.; 25 days of full power operation, according to the current license. And annual operation days will be limited no more than 100 or 125 (4 or 5 cycles) by using such core configuration due to economical reasons. However, it is desired to achieve an extension of annual operation days without increase of annual consumption of the fuel and without change of thermal power to meet increasing demand of long-term irradiation tests.

A key factor to resolve the problem is to increase the fuel burn-up which are expected to be well below the current licensed limit (50% in element-wise average) in the LEU core. Modification of the core configuration is necessary in order to increase maximum fuel burn-up, as well as duration of full power operation. The maximum fuel burn-up of 60% is already licensed for U_3Si_2-Al silicide fuel elements of JRR-3 of JAERI, of which the design and materials used are almost equivalent with JMTR LEU fuels. Therefore, we imposed the following conditions on the feasibility study about new core configuration;

i) to establish annual operation days of more than 150,
ii) maximum fuel burn-up of up to 60%,
iii) without increasing annual cost for fuel supply.

In addition, the new core configuration should fulfill the following basic design criteria for nuclear characteristic and safety evaluation criteria in the JMTR, as listed in **Table 2-1**.

Table 2-1 Basic Design Criteria and Safety Evaluation Criteria

Basic design criteria for nuclear characteristic	
Maximum excess reactivity (%Δk/k)	15.0
Shutdown margin (k_{eff})	<0.9
One rod stack margin (k_{eff})	<1.0
Maximum reactivity rate by one control rod (%Δk/k/s)	0.5

Safety evaluation criteria	
during normal operation	
Maximum fuel surface temperature (K)	473
during abnormal operational transients	
Minimum DNBR	1.5
Maximum fuel meat temperature in (K)	673

3. Neutronic Analysis

3.1 Improved Core Configurations

According to the requirements for the feasibility study, several types of core arrangements were considered. Among them, the 11-11 core which consists of 22 LEUs (2 batches) and 5 follower LEUs (1 batch), and the 8-8-8 core which consists of 24 LEUs (3 batches) and 5 follower LEUs (2 batches) were selected for final comparison about core performance and cost. In the former (11-11 core), LEUs are used for 2 cycles while the follower LEUs used only for 1 cycle. In the latter (8-8-8 core), 2 LEUs were added to the grids where aluminum reflector elements are currently placed in fuel region, and all LEUs are used for 3 cycles while the follower LEUs are used for 2 cycles. The fuel arrangements of the 11-11 core and the 8-8-8 core are shown in **Fig 3-1**.

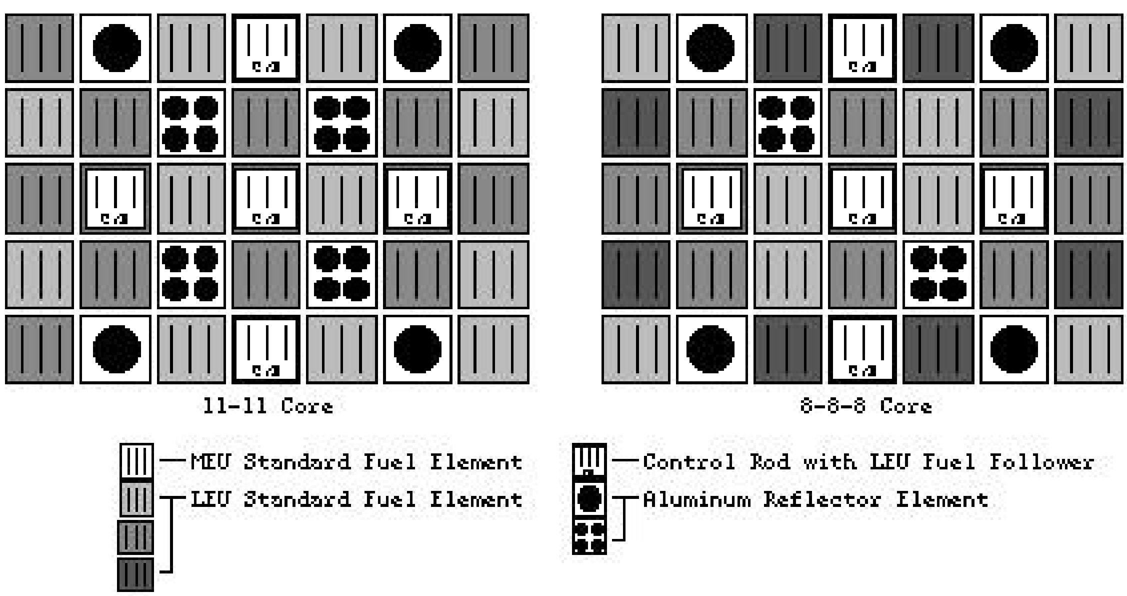

Fig. 3-1 Fuel Arrangements of 11-11 Core and 8-8-8 Core

3.2 Calculation Method

The neutronic calculations were performed by SRAC[6] code system which includes the codes and subprograms such as PIJ, CITATION, COREBN, ENDF-B/IV, etc. Cell calculation to generate 4 groups macroscopic cross section of each material were performed by using PIJ code which is based on the collision probability method. The 3-dimensional whole core calculation was performed by using diffusion code CITATION. Fuel burn-up was calculated by using COREBN code. Nuclear cross section library ENDF-B/IV was used.

3.3 Result of Neutronic Analysis

The results of neutronic calculations are summarized in **Table 3-1**. By employing either core configuration, it is possible to operate for about 32 days a cycle from the viewpoint of the excess reactivity, and the basic design criteria and the safety evaluation criteria are satisfied. However, maximum fuel burn-up in the 8-8-8 core will increase to 54%, while that in the 11-11 core was 44%. This is mainly caused by the increase of the loaded U-235 amount in the 8-8-8 core, by adding 2 LEUs.

Table 3-1 Results of Neutronic Calculations (Cold Clean State)

Core	Initial excess reactivity (%Δk/k)	Shutdown margin (%Δk/k)	One rod stuck margin (%Δk/k)	Maximum burn-up (%)	Operation days / cycle	Cycle	Annual operation days	Annual consumption of fuels
LEU Core	9.6	-16.0	-4.3	40	25	4	100	64
11-11Core	10.4	-15.3	-3.6	44	32	4	128	64
8-8-8 Core	12.5	-14.2	-2.8	54	32	6	192	63

Regarding the fuel consumption a cycle, the 8-8-8 core needs 10.5 fuels (8 LEUs and 2.5 follower LEUs) in average, while the 11-11 core needs 16 fuels (11 LEUs and 5 follower LEUs). Therefore, it is possible to operate for 192 days in maximum (6 cycles) a year by employing the 8-8-8 core with almost same annual fuel consumption with the 11-11 core for 128 days operation (4 cycle) a year. The change of excess reactivity during reactor operation cycle are shown in **Fig. 3-2**. The results of the burn-up of the LEUs and the neutronic characteristic on the 8-8-8 core and LEU core are listed in **Table. 3-2**, **Table 3-3** respectively.

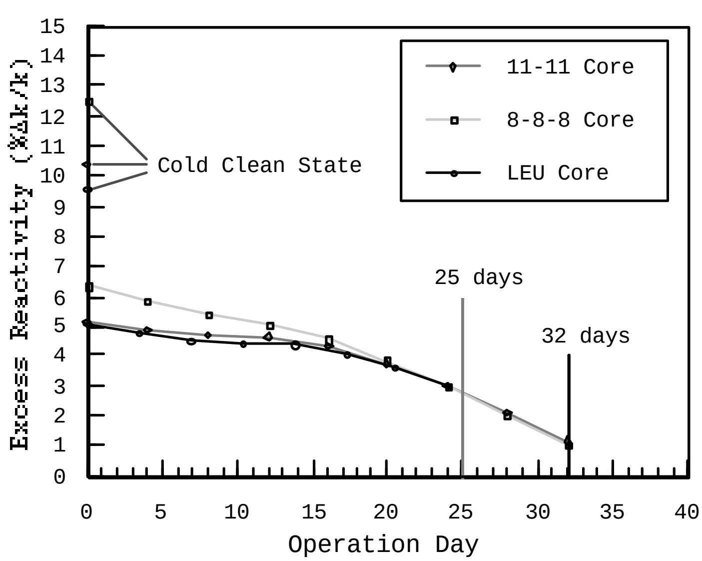

Fig. 3-2 Excess Reactivity during Operation Day

Table. 3-2
Burn-up of LEUs on 8-8-8 Core and LEU Core

Core	Average (%)	Maximum (%)	Minimum (%)
LEU Core	22	32	12
8-8-8 Core	51	54	46

Table 3-3 Neutronic Characteristic on 8-8-8 Core and LEU Core

	LEU Core	8-8-8 Core
Shutdown margin (%Δk/k)	-16.0	-14.2
One rod stuck margin (%Δk/k)	-4.3	-2.8
Control rods total worth (%Δk/k)	25.6	26.8
Maximum control rod worth (%Δk/k)	11.7	11.4
Maximum reactivity rate by one control rod (%Δk/k/s)	0.40	0.38
Temperature coefficient of reactivity (300-450 K) ($\times 10^{-2}$ %Δk/k/ C)	-2.3 ~ -4.7	-2.4 ~ -4.9
Void coefficient of reactivity (0-15 %void) ($\times 10^{-1}$ %Δk/k/%void)	-2.3 ~ -3.7	-3.0 ~ -4.1
Doppler coefficient (300-700 K) ($\times 10^{-3}$ %Δk/k/ C)	-1.7 ~ -2.6	-1.7 ~ 2.6
Prompt neutron lifetime ($\times 10^{-5}$ sec)	5.1	4.2
Effective delayed neutron fraction ($\times 10^{-3}$)	7.4	7.5

4. Thermal-Hydraulic Analysis

4.1 Calculation Method

Thermal-hydraulic calculations[7] are being performed by using COOLOD[8], EUREKA2[9][10] and THYDE-W[11] codes. The COOLOD code has a capability to analyze steady-state thermal-hydraulics in the channel of the research reactor which uses plate-type fuels. The EUREKA2 code can analyze the transient response of the core under the reactivity change caused by control rod drop or withdrawal, coolant flow change and/or coolant temperature change in LWR. The THYDE-W code can analyze the transient behavior of LWR in response to various disturbances, including the thermal-hydraulic transient such as a loss-of-coolant-accident (LOCA).

4.2 Result of Thermal-Hydraulic Analyses

According to the result of neutronic calculations, the 8-8-8 core is selected as the best candidate for future operation. Therefore, thermal-hydraulic calculations are in progress for the 8-8-8 core for safety analysis. Among the results obtained so far, transient behavior during the reactivity insertion accident, induced by sudden removal of irradiation capsule from the core, is shown in **Fig. 4-1** and **Table 4-1**. This is regarded as one of the most critical transients of the JMTR which respect to the corresponding thermal-hydraulic aspect.

In this case, the reactor is shutdown by scram at 0.135 sec in the transient, but the reactor power goes up to a maximum of 91.7 MW at 0.310 sec. DNBR, defied as the ration of critical heat flux to the surface heat flux of the fuel, decreases to the minimum value of 2.30 during the transient, due to rapid increase of fuel surface temperature and heat flux. This minimum DNBR is well above the value of safety criteria, 1.5.

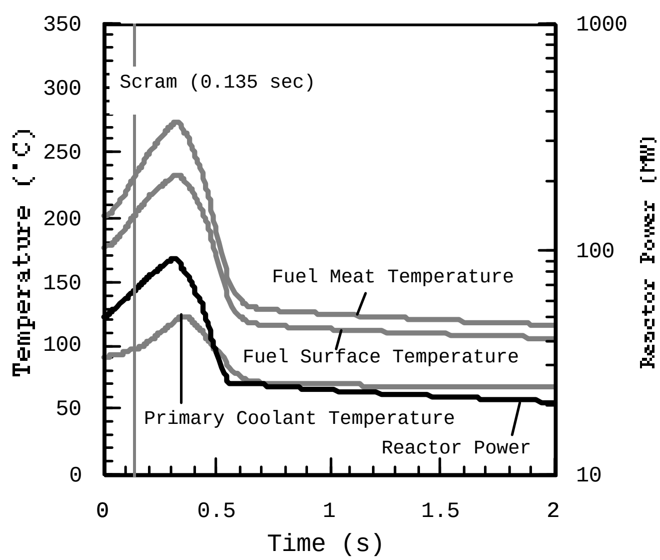

Fig. 4-1

Reactivity Insertion by Removal of Irradiation Samples

Table 4-1 Reactivity Insertion by Removal of Irradiation Samples

Maximum reactor power (MW)	91.7	0.310 sec
Maximum fuel meat temperature (C)	273.9	0.325 sec
Maximum fuel surface temperature (C)	232.6	0.325 sec
Maximum primary coolant Temperature (C)	123.6	0.355 sec
Minimum DNBR	2.30	0.225 sec

5. Conclusion

The JMTR will be operated for more than 180 days a year by employing the 8-8-8 core with annual consumption of fuels which is comparable with current status. Furthermore, it was found that thermal and fast neutron flux in irradiation region were not significantly changed. The results of neutronic and thermal-hydraulic calculations satisfy the basic design criteria and the safety evaluation criteria. The maximum burn-up on the 8-8-8 core will increase to 54%. Accordingly the application for modification of the current operation license is being prepared in order to realize the maximum burn-up over 50%.

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